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RECORDING WIND VELOCITY, DIRECTION, AND TEMPERATURE IN FIRES BY LOGARITHMIC TECHNIQUE

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Wind velocity, direction, and temperatures can vary drastically before, during, and after wild or prescribed fires. A data-recording system based on the logarithmic character of semiconductors has been developed for observing turbulent fluctuations from the mean in ratio form. The system combines a recorder, discriminator, amplifier, thermocouple, and anemometer. It has been satisfactorily field tested under severe ambient and fire conditions. This method can also be used to record and determine mixing ratios in turbulent areas for air-quality studies.

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The broad relationships between fire, weather, fuel conditions, and topography, as they affect fire behavior, are well known. Much less well known–and understood–are the specific relationships between local fire spread and intensity and microscale conditions of wind, temperature, humidity, water bodies, season, and solar insolation. Studies of local climate over areas of less than 10 square kilometers have shown that the atmospheric eddy structure could be identified and related to local terrain features and the over-all large scale synoptic weather patterns.[1] The time scale of these eddies was on the order of 1 hour, and their size was on the order of tenths of kilometers. After the experimental fire was ignited, unexpected and "anomalous" wind patterns were generated by the fire. That work demonstrated the need for a method in fire research of recording strong winds to at least 75 meters per second and high temperatures as great as 1600° C. Yet the additional requirement of a means for measuring climatological conditions before and after a fire still had to be satisfied.

To measure the extreme deviations in temperature and wind found in a fire environment, we developed a technique, based on the logarithmic characteristics of semiconductors, that combines an electronic recorder, direction discriminator, logarithmic amplifier, thermocouple, and anemometer. Relative turbulent fluctuations are recorded because the data output is in ratio form. This method can also be used to record and determine mixing ratios in turbulent areas for air-quality studies.

DESIGN CONSIDERATIONS

The principal constraint in our design was the need for the method to function properly during a fire. Fires ordinarily burn best under conditions of atmospheric instability. Therefore, we used the Richardson

number, Ri in terms of the height z of the instruments and the Monin-Obukhov length L, as the basis for determining the accuracies we required:

$$Ri = (z/L) \tag{1}$$

$$L = \frac{-T}{kg} \frac{(u^*)^3}{\overline{w'T'}} \tag{2}$$

in which T is the absolute temperature, $(u^*)^3$ is the friction velocity, g is the acceleration due to gravity, k = 0.37 is the von Karman constant, and $\overline{w'T'}$ is the average of the product of the simultaneous fluctuation of the vertical velocity w′ and the temperature fluctuations T′.

The accuracy requirements for sensors used in the technique can be estimated by logarithmically differentiating Equation 1. The result in finite difference form is approximately

$$\left|\frac{\Delta Ri}{Ri}\right| = \frac{\overline{T'}|\Delta w'| + w'|\Delta T'|}{\overline{w'T'}} + \frac{|\Delta T|}{\overline{T}} \tag{3}$$

assuming that w′ and T′ are independent as is indicated by Monin and Yaglom.[2]

Expected values of temperature in fires burning in chaparral vegetation have a maximum of 1800° K although average temperatures are much lower–about 400° K. Vertical winds are on the order of 50 m/sec while the mean fluctuations are on the order of 10 m/sec in turbulent fires.

These values, when inserted in Equation 3, show the relative contribution to measurement error in the Richardson number

$$\left|\frac{\Delta Ri}{Ri}\right| = \frac{|\Delta w'|}{10} + \frac{|\Delta T'|}{100} + \frac{|\Delta T|}{400} \tag{4}$$

An analysis of ambient atmospheric conditions leads to a similar conclusion about the effect of measurement error. The fluctuations in the ambient atmosphere are about from 10 to 100 times smaller than in a fire. But the relative importance of the terms is preserved. From these relationships we determined that a logarithmic output would give sensitivity in the ordinary ambient ranges of temperature (−40° to 50° C) and wind (0 to 5 m/sec) yet still preserve the measurement capability with the same relative accuracy at the extreme fire values. This provided sufficient flexibility so that we could use this technique for measuring site climatology before and after a fire as well as *in situ* characteristics of the fire.

In our initial field tests, we were uncertain about our ability to protect the recorders from dust and heat because we knew of no previous accurate measurements of both wind and temperature in the flames of wildland fires. Further, instrumentation had to be exposed over long periods in areas subject to vandalism. For this reason, we decided to degrade the pulsed anemometer response by using a discriminator circuit to drive Esterline Angus (E/A) Model AW recorders,[3] which were semi-expendable (*fig. 1*). This

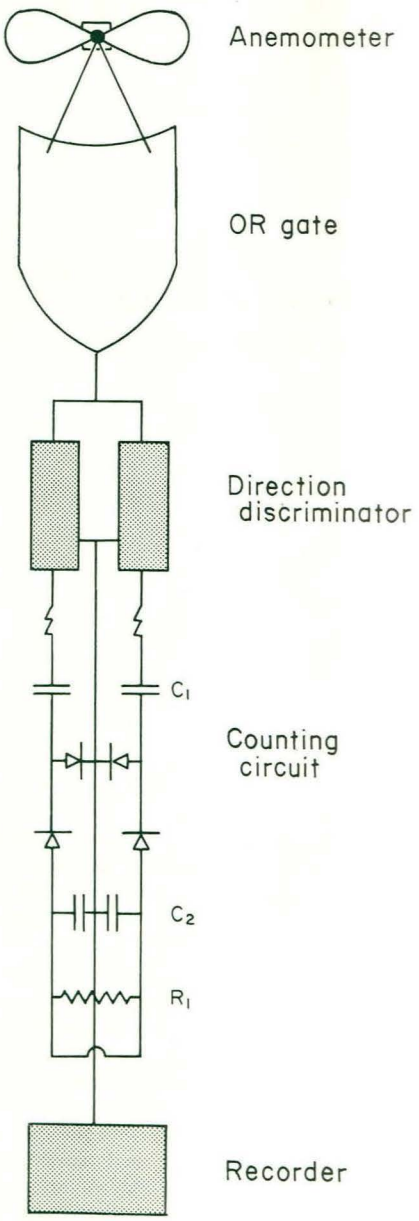

Figure 1—The anemometer measures windspeed and direction. The direction discriminator determines the path followed by the counting circuit. Output is recorded by the electronic strip-chart recorder.

addition imposed increased high electrical-current requirements because of the low impedance of the strip-chart recorders.

WIND COMPONENTS

The anemometers have a fixed axis, and measure, in an orthogonal coordinate system, three components of wind (north-south, east-west, up-down)[4]. The windspeed is sensed by switches that are opened and closed by the rotation of the anemometer. The switches may be magnetically, mechanically, or electrically operated. They are closely spaced so that the direction of rotation may be sensed by determining which switch operated first. The weight, power, and other requirements made it desirable for us to have the zero wind in the middle of the strip charts on the recorders. Therefore, we linearized the anemometer output between 0 and 5 m/sec while maintaining the logarithmic character at higher speeds (*fig. 2*).

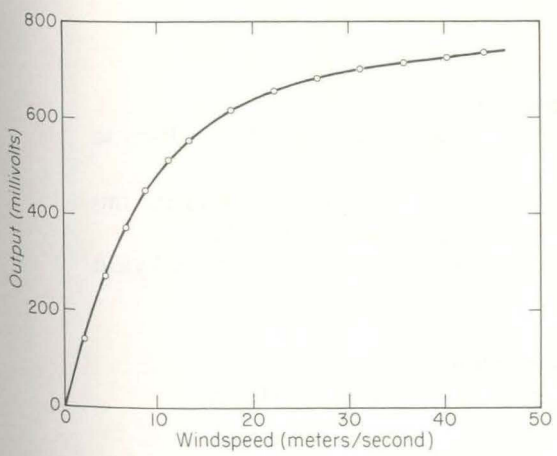

Figure 2—The anemometer response to wind is linear for the first 5 m/sec and logarithmic for higher values.

The size of the coupling capacitor (c_1), storage capacitor (c_2), and bleed resistor (R_1) are directly related to (a) the response of the system, and (b) the output power required to drive the recorders. In our design, we used c_1 = 6.8 microfarads, c_2 = 30 microfarads, and R = 1450 ohms. These design values give a circuit response time of 0.043 seconds.

The frequency of the anemometer signal may be as low as 2.6 hertz at windspeeds of 2.25 m/sec. The coupling capacitor must, therefore, have sufficient capacity to allow c_2 to acquire the charge necessary to power the 1-milliampere recorder used in the test unit. Other values of c_1 and c_2 may be used when recording on a tape or using a system with a higher impedance input.

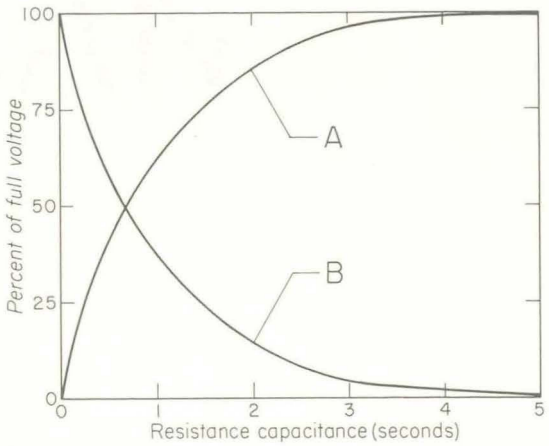

Figure 3—The voltage in a resistance capacitance decreases or increases exponentially with time; curve A is rise time of circuit, curve B is decay time of circuit.

In most electronic circuits with integrating resistance capacitance (RC), the current required to drive a recording system is produced by charging capacitor c_2 over a relatively long period of time and then discharging it at a fast rate. We inverted this process and operated at a continuous discharge rate and charged c_2 in a short time. Thus, at any given time, the voltage across c_2 depends upon the applied voltage as well as upon the RC time constant. The charging of c_2 continues as long as c_1 has a charge greater than c_2. The charge varies because variations in the rotation rate of the anemometer supply a varying charge to c_2 in proportion to the rate of rotation. Because the output to the recorder varies according to this charge, it represents the revolutions per second of the anemometer corresponding to the windspeed.

Since this charge and discharge cycle is representative of the voltage times the rate applied to c_1, the output will fit a predefined charge curve. If this curve is reversed, it then becomes a decay curve and represents the discharge of c_2. The curve is used in calibrating the anemometer's rate of rotation in relation to the output. The anemometer's windspeed calibration in terms of rotation rate is performed separately. If curve A in *fig. 3* is inverted, it becomes curve B, which is a better representative of the voltage e left after a period of time t. The equation of this curve is $e = E \exp(-t/RC)$, in which E is the voltage applied to c_1 and e is the reduced voltage after time t. The value of t/RC is the ratio of actual time of decay, t, to the RC time constant. The negative exponent $-t/RC$ indicates a declining exponential or logarithmic curve. This curve can be plotted on logarithmic paper with t as vertical axis and m/sec as horizontal axis. From

this graph, a chart can be made to quickly determine the windspeed for any given system voltage output (*fig. 4*).

TEMPERATURES

The temperature was sensed by a radiation-compensating thermocouple[5] (*fig. 5*). Amplifiers based on the logarithmic characteristics of the transistor base were used to record the temperatures ranging from ambient to fire temperatures (10° to 1000° C). Our test unit followed the design principles outlined by Patterson[6] and Huehne.[7]

To obtain the output needed to drive the 1400-ohm impedance E/A recorder, we pre-amplified the output from the thermocouple by a factor of 10. The data were then fed into the logarithmic amplifier after which they were amplified by a factor of 3 before they were recorded. This last step is not necessary if a high impedance recorder is used.

The output of the logarithmic amplifier (millivolts) varied nearly linearly with the logarithm of temperature (degrees C). The temperature of the test thermocouple was measured by taking the millivolt reading at the output from the compensating junction and comparing this reading with Table IX in Omega's *Temperature Measurement Handbook.*[8] The reading was recorded and plotted on the horizontal axis (*fig. 6*).

CONCLUSIONS

The data system has operated continuously over a 2-year period without a single failure. It has survived winds up to 75 m/sec and temperatures up to 1200° C with no damage. The system has proved particularly advantageous in recording the turbulent fluctuations because its output offers an easy means for observing these fluctuations against the mean in a ratio form. Where primes indicate fluctuation, the over-bar signifies the mean values. This form preserves the relative accuracy and precision of the data–as required by turbulent theory.

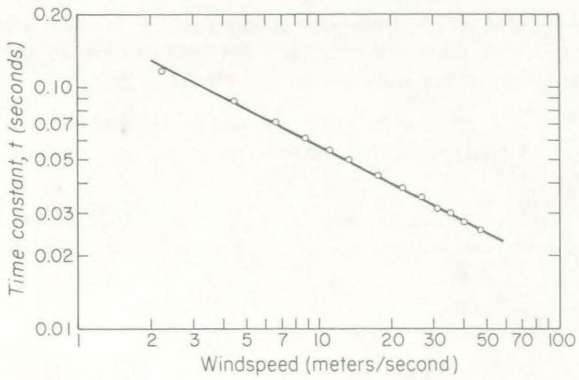

Figure 4—Windspeed for a given voltage output can be computed by relating time for voltage decay to 0.37 of its initial value.

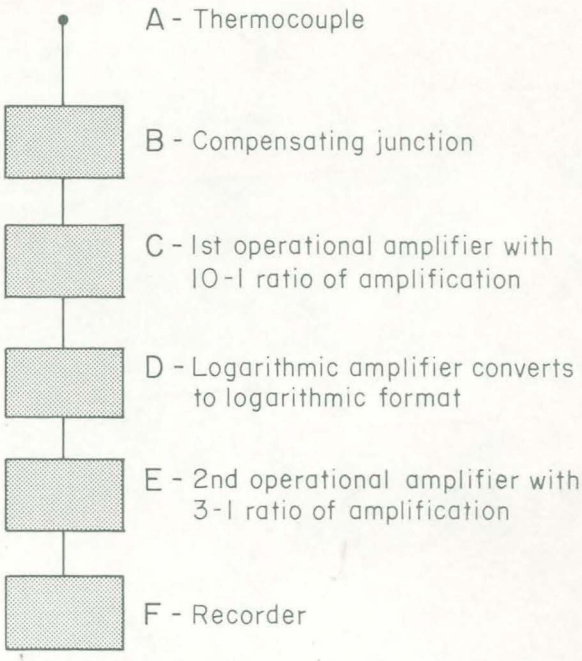
A - Thermocouple
B - Compensating junction
C - 1st operational amplifier with 10-1 ratio of amplification
D - Logarithmic amplifier converts to logarithmic format
E - 2nd operational amplifier with 3-1 ratio of amplification
F - Recorder

Figure 5—The radiation-compensating thermocouple senses temperatures. Amplifier system transformed the data to a logarithmic output which was then recorded by the electronic strip-chart recorder.

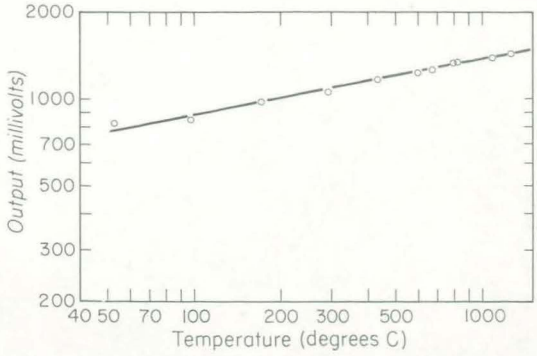

Figure 6—The output of the logarithmic amplifier (millivolts) varied nearly linearly with the logarithm of temperature (degrees C).

NOTES

[1] Countryman, Clive M., and Mark J. Schroeder. 1958-1959. *Prescribed burn fireclimate survey.* Papers 29, 31, 34, 35. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

[2] Monin, S. S., and A. M. Yaglom. 1971. *Statistical fluid mechanics: mechanics of turbulence.* 769 p. MIT Press, Cambridge, Mass.

[3] Trade names and commercial enterprises or products are mentioned solely for information. No endorsement by the U.S. Department of Agriculture is implied.

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[8] Omega Engineering, Inc. 1973. *Temperature measurement handbook.* Stamford, Conn. p. 9-10.

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